pervading molecular effect. This conception fully explains our results of two years ago that bars of ice with the axis transverse yield neither to pull nor thrust. If we had tried a bar with the optic axis oblique, it would have stretched readily enough.

The rate of distortion was very irregular, showing a strong tendency to increase with the length of time for which the weight was applied. When extra weight was put on, the rate increased more than in proportion to the weight itself, but less than in proportion to its square. The effect of temperature was generally masked by these others, but there could be no doubt of its existence; the rate at $-2°$ being in one case twice or three times as great as *cæteris paribus* at $-10°$.

Plasticity, due to sliding planes (Gleitflächen), has been shown to exist in rock salt, Iceland spar, &c., by Reusch and others. In rock salt these planes are parallel to the faces of the rhombic dodecahedron, and in general there are several different sets. As long ago as 1867, Reusch suggested their existence in ice as a means of explaining the observed plasticity. I find that the observation that an ice crystal is plastic was made by Hagenbach in 1881, but he did not further investigate the matter.

VII. "Preliminary Note on a New Magnetometer." By W. Stroud, D.Sc., Professor of Physics, Yorkshire College, Leeds. Communicated by Professor A. W. Rücker, F.R.S. Received May 30, 1890.

The determination of the horizontal component of the earth's magnetic field is of great importance, not only for the purpose of magnetic surveys, but also for the determination of the absolute strength of an electrical current, a measurement frequently required, not only for scientific work of various kinds, but also for the calibration of ammeters and voltmeters, and other electrical measuring instruments.

The usual method of measuring this important quantity is that of Gauss, but the method is so long and laborious, and the apparatus requisite for accurate determination so expensive, that the measurement of H is avoided whenever practicable. The writer, having devised an instrument capable of determining H with great expedition and accuracy, ventures to think that a description of the instrument may not be without interest.

Gauss's method consists, as is well known, in finding (1) the deflection produced upon a small magnetic needle by a large magnet of moment M, placed at a known distance from, and in a certain position with regard to, the needle; and (2) the time of vibration of the deflecting magnet when suspended so as to oscillate in a horizontal

plane about its position of equilibrium. The first operation gives the value of M/H, or rather *would* give it if the distance between the poles of the deflectors were known. To measure and allow for this requires a second experiment, when the distance from the needle is altered, and the new deflection read. In this way two simultaneous equations are obtained, from which, by elimination of the distance between the poles, an equation is obtained involving M/H as the only unknown. The second operation gives the product of M and H, or rather *would* give it if the moment of inertia of the magnet about its axis of oscillation were known. As this quantity is not directly determinable, a second equation has to be obtained by increasing the moment of inertia by a known amount, and determining the new time of vibration. In this way two more simultaneous equations are obtained, from which, by elimination of the unknown moment of inertia, the value of MH is obtained in terms of measurable quantities.

Doubtless Gauss's method is excellent when the moment of inertia, as well as the distance between the poles of the deflector, is wanted, but when these quantities are not required (and they never are) a more direct method is very desirable. In a magnetic survey, no doubt, the determination would be shortened by measuring, once for all, the moment of inertia of the deflector, and possibly the distance between the poles.

In place of the laborious dynamical method of measuring MH, various statical methods have been suggested and employed, notably by suspending the deflecting magnet bifilarly and approximately east and west. The instrument to be described consists of a deflecting magnet of peculiar form, suspended bifilarly and approximately east and west; in this case the lower end of the bifilars will be turned through an angle which forms a measure of MH. This magnet at the same time acts at a known distance as deflector to a little magnet, the deflection of which is a measure of M/H. Hereafter the deflecting magnet will be, for brevity, referred to as the "magnet," the little deflected magnet as the "needle."

The magnet consists of a piece of fine pianoforte wire, some 100 cm. long, and 0·06 cm. in diameter, bent into the form of a circle, or approximately so, the two ends being soldered together "end-on," with no overlap. This is magnetised similarly to a Gramme armature, with a north and south pole at opposite ends of a diameter (by placing it with this diameter between the two opposite poles of a weak electromagnet), and so suspended from the bifilar arrangement, that, when the bifilars are vertical, the magnet lies with its plane vertical, and approximately east and west, and with its magnetic axis approximately horizontal. In its position of equilibrium, the couple which the earth exerts upon it is MH $\cos\theta$, where M denotes the

magnetic moment of the magnet, H the horizontal component of the earth's magnetic field, and θ the azimuthal deflection of the magnet. The couple exerted by the weight W attached to the bifilars is $\frac{\mathrm{W}dd'}{4l}\sin\theta$, where d, d' are the distances between the upper and lower ends of the bifilars, and l is their length. Hence we get

$$\mathrm{MH} = \frac{\mathrm{W}dd'}{4l}\tan\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1.).$$

At the centre of the circular magnet there is suspended the little needle, which will be deflected from the magnetic meridian through an angle ϕ. In its position of equilibrium the couple exerted by H is equal to the couple exerted by the magnet. The former couple is $m\mathrm{H}\sin\phi$ where m is the magnetic moment of the needle. Let us imagine for the moment that the whole of the magnetism of the circular magnet is concentrated at two points, one at each end of a horizontal diameter, and let each pole have a strength μ. The intensity of field at the centre is $\frac{\mu}{r^2}$ from each pole, or together $\frac{2\mu}{r^2}$, where r denotes the radius of the circular magnet; so that, neglecting the distance between the poles of the needle, the couple exerted on it by the magnet will be

$$\frac{2\mu m}{r^2}\cos(\phi-\theta) \quad \text{or} \quad \frac{\mathrm{M}m}{r^3}\cos(\phi-\theta);$$

$$\therefore \frac{\mathrm{M}}{r^3}\cos(\phi-\theta) = \mathrm{H}\sin\phi;$$

$$\therefore \frac{\mathrm{M}}{\mathrm{H}} = \frac{r^3\sin\phi}{\cos(\phi-\theta)},$$

whence

$$\mathrm{H}^2 = \frac{\mathrm{W}dd'}{4lr^3}\,\frac{\tan\theta\cos(\phi-\theta)}{\sin\phi} \quad \ldots\ldots\ldots\ldots \quad (2.).$$

If the distances between the bifilars and their length be so adjusted that $\phi \fallingdotseq \theta$, *i.e.*, that the magnet and the needle turn through approximately the same angle in the same sense, then

$$\mathrm{H}^2 = \frac{\mathrm{W}dd'}{4lr^3}\cdot\frac{\tan\theta}{\sin\phi}.$$

Or, if the deflections θ, ϕ be read off in the usual way with telescope or lamp and scale, then, to a certain degree of approximation,

$$\mathrm{H}^2 = \frac{\mathrm{W}dd'}{4lr^3}\cdot\frac{\theta}{\phi}.$$

Thus H is determinable in terms of a mass, the value of the acceleration of gravity at the place, certain distances, and the ratio of two deflections.

A possible modification of the method consists in making θ accurately equal to ϕ by varying W, d, or l, or, better, by turning the upper end of the bifilars through a known angle. So far, however, the writer has preferred to adjust the constants of the instrument so that for $H = 0{\cdot}18$, θ shall be nearly equal to ϕ. It will be noticed that if telescope and scale be used there is no necessity to determine the distance of the scale from the magnets except very roughly indeed, as we are requiring the ratio of the tangent and the sine of two not very large angles. Thus the necessity of measuring two angles of deflection instead of one as in Gauss's method is really an advantage, as it obviates the necessity of determining either angle absolutely.*

The special feature of the circular form of deflecting magnet is this—that it is a matter of utter indifference what the distribution of magnetism in it may be, provided it be circular and the little needle be at the centre. This can be readily seen, for if we imagine some north-seeking magnetism situated at an angular altitude χ referred to the centre, the earth's moment on this will vary as $\cos \chi$, but at the same time the intensity of field at the centre resulting therefrom and measured horizontally varies as $\cos \chi$ too, so that not only is the position of the magnetic axis unimportant, but the distribution of magnetism may even be irregular without invalidating equation (2). Moreover, if we are careful in the magnetisation to get the poles in something like the right positions, it is not necessary that the magnet should be absolutely circular; all that is necessary is that the magnet should be circular only in the neighbourhood of the poles. In the above equations, then, r will stand for half the polar diameter of the magnet. Again, with a magnet of moderate dimensions the needle need not be placed rigorously at the centre, since it is in a *minimum* field arising from the action of the two opposite poles on opposite sides. To illustrate this, we may take the case of a magnet, not unduly large, 30 cm. in diameter; then if the little needle, instead of being at the centre, is displaced horizontally 1 cm. on either side, allowing, in fact, a range of 2 cm., the intensity of field at the centre is only increased by 1·2 per cent., so that H will be too small by 0·6 per cent. The needle can easily be arranged within 2 mm. of the centre, and in this case H will only be affected to 1 part in 11,000. It will thus be seen that even for the most accurate work a comparatively small magnet may be used, and the little needle need not be placed rigorously at the centre. All the ad-

* It must be understood that the writer is not recommending that small angles of deflection should be used (see Note appended).

vantages of this form of deflector have not even yet been enumerated. The circular magnet may be made, or, rather, requires to be made, very weak indeed; this arises from the fact that the action of the two poles on the needle is a *summational* instead of being a *differential* one, as in the usual method of performing the deflection experiment. There can be little doubt, too, that it is an advantage rather than the reverse to use only weak magnets in determining the value of H. Lastly, any variation in magnetic moment arising from changes in temperature or other causes does not affect the determination, and, what is a matter of some importance in accurate determinations, there is no correction corresponding to that required in Gauss's method for the varying inductive action of the earth in the different positions which the deflector assumes with reference to the magnetic meridian.

Description of Instrument.

The instrument consists of a rectangular wooden box, ABCD, fig. 1, mounted on levelling screws, and provided with a plate-glass window in one of the large vertical sides, which can be opened for obtaining access to the interior. Attached to the upper side of this box is a second, EF, also provided with a door for adjusting the bifilars G, G in position. The little needle N is suspended at the centre of the large box by a silk fibre some 10 cm. long attached to a brass arm, K, which is screwed into the side of the box opposite to the plate-glass door. Fastened to the needle at right angles to its magnetic axis is a plane mirror (P), 1 cm. in diameter. The needle and attached mirror are prevented from turning completely round by a forked piece of wood, F, which also enables the experimenter to observe when the needle is at the centre of the box.

Soldered to the large circular magnet MMM are two hooks of brass of an indented V-shape, H, H, figs. 1 and 2. These are for suspending the magnet from the brass bar L, which forms the lower end of the bifilar arrangement (figs. 1 and 2). The form of this bar is a knife-edge of brass with a V-notch, Q, near one end, so made with the object of enabling the circular magnet to be unhooked and reversed in position. This eliminates any error arising from the circumstance that the plane of the circular magnet may not be placed accurately magnetic east and west when the bifilars are vertical. A long aluminium wire, W, riveted at each end to the bar, descends in the form of a wide loop, and carries a plane mirror, R, to enable the deflection of the circular magnet to be read off. This mirror is placed just below the mirror P, previously mentioned, so that only one telescope is needed in reading the deflections of both needle and magnet. Soldered to the bar is a strip

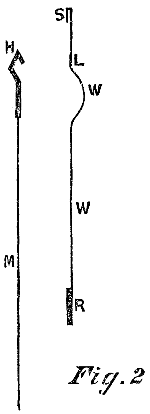
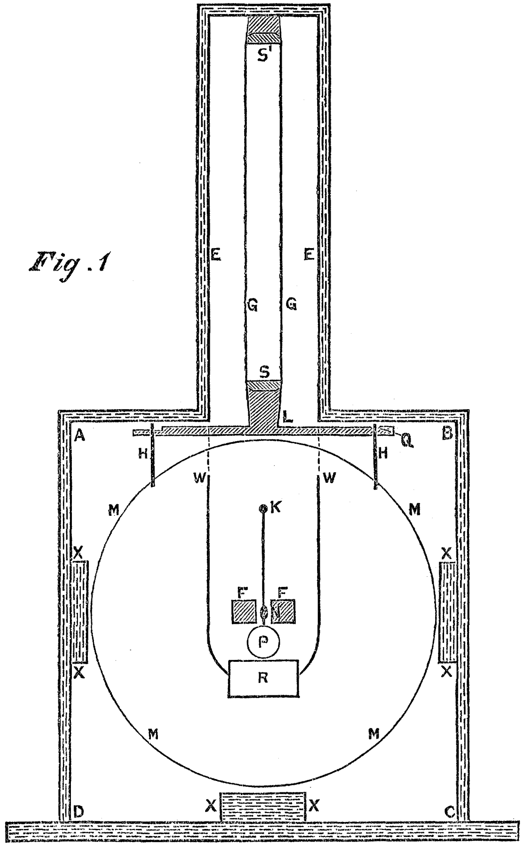


Fig. 2

Fig. 1



of thin sheet brass, some 1·3 cm. in width, which is bent over at the top to form a wide hook, S, figs. 1 and 2, under which the bifilars pass. At the top of the instrument is attached a similar hook, S′, from which the bifilars are suspended. The widths of these hooks (which form the distances between the bifilars at the top and bottom) can be read with a micrometer gauge with certainty to 0·001 cm., and by estimation more accurately. The circular magnet, bar, and attached mirror are made as light as they can possibly be made.

Pieces of wood (X, X) are attached to the bottom and two shallow sides of the box in which the circular magnet is suspended in such a way as to leave only about 0·1 cm. clearance for the magnet when it is oscillating before coming to rest. As the needle, too, can only vibrate freely when within a millimetre or so of the centre, it is clear

no observation can be made unless the needle is within at the most 2 mm. of the centre of the magnet.

To read the deflections θ, ϕ, a lamp and scale, or telescope and scale, may be used. A slight difficulty arises with a single telescope and a single scale when setting up the instrument for the first time, owing to the two mirrors not usually making the same or sufficiently nearly the same angles with the vertical. Either two telescopes and one scale, or two scales and one telescope, may be used; but the best plan is to use one telescope and one scale, and to bend the aluminium wire supporting the lower mirror till the latter occupies a suitable position with respect to the vertical.

Corrections will have to be made for (1) the torsion of the silk fibre suspending the needle, (2) the torsion of the silk fibres suspending the magnets, and (3) the couple which the little needle exerts on the magnet. So far as the first two corrections are concerned, they can be allowed for in the ordinary way. For the present instrument the first correction affects H to the extent of one part in a thousand; the second is utterly negligible. It is a matter of interest to determine the magnitude of the couple exerted by the needle on the magnet compared with that exerted by the earth. Now, the earth's couple on the magnet $= \mathrm{MH}\cos\theta$, and on the needle $= m\mathrm{H}\sin\phi$, so that the fractional error in equation (1), made by neglecting this effect, would be $m\sin\phi/\mathrm{M}\cos\theta$, or, practically, $m\phi/\mathrm{M}$, which, for the present instrument, would amount to about $\frac{1}{360}$, since by experiment $\mathrm{M} = 91$ c.g.s. units, and $m = 1{\cdot}5$ c.g.s. units and $\phi = 10^\circ$. This correction is then, by no means, negligible, since it would affect H to the extent of 1 in 700. The error arising from this source could, however, be made very much smaller by diminishing m or, preferably, by increasing M.

The following results have been obtained for the value of H in the physical laboratory of the Yorkshire College, Leeds, which was designed by Professor Rücker, so as to be as free as possible from iron which could not be removed if necessary. The instrument was set up in the middle of the room, the nearest iron being some 4 metres distant, and consisting of a grate, roughly in the same magnetic meridian as the instrument. This will clearly give a higher value for H than if the grate had been removed; but the object of the experiments was to determine H, not for Leeds, but for one place in the physical laboratory.

I. May 17th, 1890. Scale, a metre long, placed roughly 97 cm. from the centre of the instrument.

	cm.
Reading for magnet before reversal ..	10·33
,, ,, ,, after ,, ..	52·59
Difference ..	42·26

		cm.
Reading for needle before reversal....		6·21
„ „ „ after „		88·69
	Difference....	82·48

Weight suspended from bifilars = 11·37 grams.

Length of bifilars measured by cathetometer = 30·07.

Distance apart of bifilars at top = 0·5092 inch = 1·293 cm.

„ „ „ below = 0·5173 „ = 1·314 „

Diameter of circular magnet = 27·50 cm.

From which data H = 0·1803.

II. May 20, 1890. 4 P.M. Scale 2 metres long, placed 2 metres from instrument. Distance between bifilars below altered and weight changed in consequence.

		cm.
Reading for magnet before reversal ..		153·66
„ „ „ after „ ..		77·34
	Difference ..	76·32

		cm.
Reading for needle before reversal....		191·76
„ „ „ after „		25·40
	Difference....	166·36

Weight = 11·89 grams.

Distance between bifilars below = 0·5126 inch = 1·302 cm.

Length of bifilars = 27·81 cm. Other constants as before.

H = 0·1805.

III. May 20. 5 P.M. Constants same as in II.

		cm.
Reading for magnet before reversal ..		153·69
„ „ „ after „ ..		77·72
	Difference..	75·97

		cm.
Reading for needle before reversal....		192·51
„ „ „ after „		26·67
	Difference....	165·84

H = 0·1803.

By comparing experiments II and III, it would seem that the magnetic moment of the magnet had altered, probably owing to handling. This alteration does not, however, in any way affect the result, except in so far as the magnet itself expands with rise of temperature.

Seeing that these results have been obtained with a rough instrument made on the premises, and with very inferior mirrors, the method seems very satisfactory.

For the determination of the strength of a current in absolute measure the writer would suggest placing two coils of wire, each of known geometrical form, the one with its plane in the magnetic meridian on the east side of the instrument, the other similarly on the west side with their axes passing through the centre of the needle. The two coils attached to the instrument would form in fact a Helmholtz standard galvanometer with the addition of the circular magnet with bifilar suspension. Observations of (1) the deflection of the circular magnet on reversal; (2) the deflection of the needle under the action of the circular magnet; (3) the deflection of the needle when the circular magnet is removed altogether and the current traverses the coils will give the value of the current in absolute measure correct, it is believed, to one part in a thousand if the geometrical constant of the coils can be determined to that degree of accuracy.

Now an interesting point arises in connexion with the possible accuracy attainable by this method. The writer believes that with apparatus of the dimensions described there is no difficulty in determining each one of the quantities d, d', l readily to the $\frac{1}{1000}$ part. With a telescope the deflections θ, ϕ can certainly be relied upon to that degree of accuracy, at all events if θ, ϕ are each more than 5°. A little uncertainty arises in connexion with the measurement of r, and this is very important, as $\mathrm{H} \propto r^{-\frac{3}{2}}$. Is the pole to be considered at the middle of the wire of the circular magnet, or nearer the surface of the wire, and if so on which side? This question cannot be answered with certainty. Reckoning from the middle of the wire in determining the distance between the poles, the maximum error possible in a wire of 0·06 cm. diameter is 0·03 cm., and this with a radius of 13 cm. gives 1 part in 300 as the extreme error that could be made in H. We may, however, be nearly certain that the pole cannot be more than half the radius of the wire distant from its centre. We may therefore say that about 1 in 500 represents the *possible* error in H arising from this cause. Clearly, however, it is advisable on all accounts to replace the circular wire of the magnet by a flat steel ribbon bent into the form of a circle.

It will be noticed that the effect of variation in temperature in altering the value of the constant of the instrument can be allowed for with great accuracy, as the coefficients of expansion of the

different metals used in the construction of the instrument are known with sufficient accuracy. It is probably better not to include the length of the bifilars in the constant of the instrument, except for rough work, as both variation in temperature and in the hygrometric state of the air will produce sensible alterations in length.

An objection may be taken to the method when very accurate determinations are desired on the ground that a knowledge of the value of the acceleration of gravity at the place of observation is requisite before absolute determinations can be calculated. The writer believes, however, that a quartz fibre suspension for the magnet would be preferable to the bifilar for magnetic survey work. It is perhaps needless to say that provision would be made for clamping magnet and needle during transport. To convert the readings of the instrument into absolute measure, it will be necessary to determine H at as nearly as possible the same place and at the same time by comparing the indications of the instrument with those of a large standard instrument of the bifilar type previously described.

In connexion with the erection of such a standard instrument, the points to be borne in mind are, that all corrections arising from (1) torsion of the silk fibres, (2) uncertainty in the position of the poles of the large magnet, (3) couple exerted by needle on magnet, shall be made as small as possible. To effect this, the bifilars should be longer, the magnet should be made of thin band steel instead of wire, and the diameter of this magnet should be increased in order that r may be measured more accurately, and in order that the magnetic moment of the large magnet may be increased without unduly increasing the deflection of the needle. The writer is at present engaged in erecting such an instrument in the physical laboratory of the Yorkshire College, and hopes to be able to attain with it results approximating in accuracy to 1 part in 10,000.

In conclusion, the present method of determining H is believed to be very much superior to Gauss's in the following respects:—

(1.) The necessity of making a determination of a time of vibration (always a tedious operation) is avoided.

(2.) The determination of a moment of inertia is avoided.

(3.) The determination of the distance between the two poles of the deflector is avoided.

(4.) Variation of magnetic moment of the deflector during the progress of an experiment produces no error; neither does variation in inductive action of the earth produce an error.

(5.) The magnet needs only to be very feebly magnetised, as its action on the needle is due to the *sum* of the actions of the two poles.

(6.) The time occupied in a determination of H is only a few minutes when once the constant of the instrument has been determined.

(7.) The instrument, exclusive of telescope and scale, can be made at a very small cost.

[*Note added June* 17.—In comparing the accuracy of the proposed instrument with the Kew, it is necessary to distinguish between the determination of N in absolute measure, say, for laboratory purposes, such as the measurement of the strength of electrical currents, and determinations where the requirements are the estimation of differences in the value of H at different stations, say, for the purposes of magnetic surveys. For an absolute determination a great deal can be said for an instrument in which the only measurements are certain angles, certain distances, and a certain weight, and which does not require a determination of the influence of the earth's inductive action on the magnet, nor of the variation of the magnetic moment of the magnet with temperature, nor of the position of the poles of the magnet. With reference to magnetic survey work, a comparison may be instituted between the Kew instrument and that under discussion by assuming the constants of each to be known; then in each case angular deflections are being measured, and other things being equal, the accuracy obtainable will be approximately proportional to the magnitude of the angles observed. Now in the Kew instrument, the deflection produced by the deflector in its near position is about 24°, and in its far position about 12°. Something like the difference between these deflections, or 12°, will represent the order of angle to be estimated as accurately as possible. It is not possible in the Kew instrument to materially increase these angles without unduly increasing the influence of the distribution of magnetism in the deflector. In the present instrument there seems to be no reason why deflections of 45° or thereabouts should not be obtained. This reasoning would seem to show that the present instrument could be made considerably more sensitive than the Kew.

It need, perhaps, scarcely be mentioned that the writer is not advocating the use of telescope and scale for measuring the angular deflections in preference to an azimuth circle. The former method (quite unsuitable for measuring large angles) was only adopted in the first instance to roughly test the capabilities of the instrument in the absence of any graduated circle. In a final instrument all the deflections will be referred to a graduated azimuth circle, as in the Kew instrument at present.

A few points of detail may be just mentioned in conclusion :—(1.) To eliminate any error arising in the bifilar suspension from the distance between the centres of the silk fibres being slightly different from the breadth of the metal hook, the writer proposes to control the distance between the upper ends of the bifilars from the *outside* by an aperture in a piece of metal, and to control the distance between

the lower ends from the *inside* by the breadth of the hook. If now the distances between the fibres top and bottom are nearly the same, no sensible error will be made by taking the product of these distances as equal to the product of the breadth of the hook and the width of the metal aperture. (2.) To render the controlling couple produced by the deflected bifilars independent of temperature, it is proposed to select metals with appropriate coefficients of expansion for regulating the dimensions of the bifilars top and bottom, and to alter the length of the silk fibres by an appropriate arrangement, so that a pointer attached to the hook at the lower end shall always come to a fiducial point upon a strip of brass attached to the metal framework which forms the upper suspension. The neatest way of doing this seems to be to cement the plane and silvered side of a short-focus plano-convex lens to the strip of brass, and to arrange its position with reference to the pointer so that the tip of the latter is exactly in the focus of the lens. In this position the tip and its reflected image will appear just in coincidence, and if necessary a lens may be provided in the side of the instrument for observing the relative positions of the pointer and its image and adjusting them to coincidence.]

VIII. "On the course of the Fibres of the Cingulum and the Posterior Parts of the Corpus Callosum and of the Fornix in the Marmoset Monkey." By Charles E. BEEVOR, M.D., F.R.C.P. Communicated by Professor FERRIER, F.R.S. Received June 12, 1890.

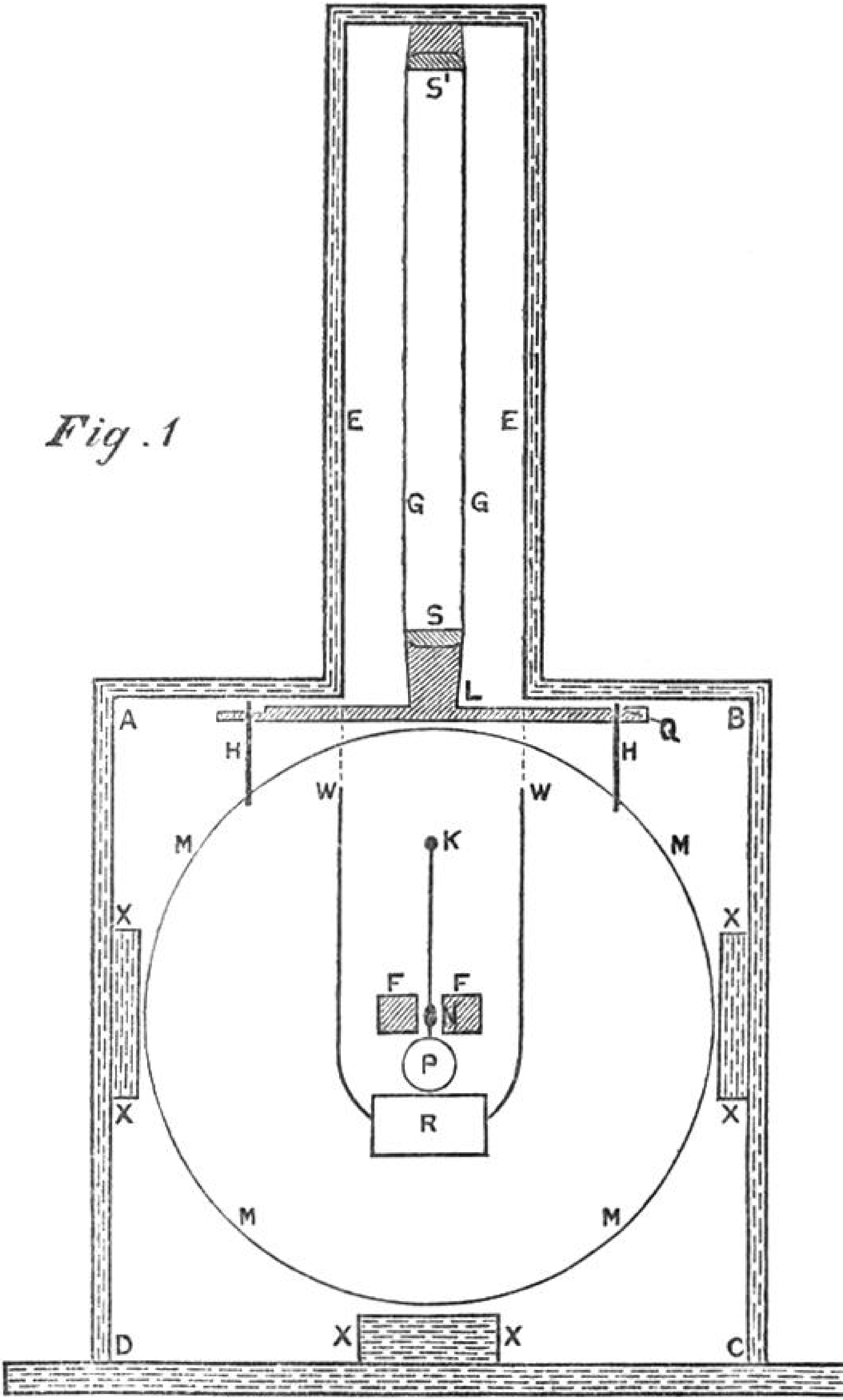
(Abstract.)

This paper has for its scope the investigation by the microscope of the course of certain fibre-tracts in the brain which have not hitherto been minutely examined.

After an introduction showing the difficulties of tracing these fibres by dissection and by other means, the *method of investigation* is given. This consisted in cutting serial sections of the brain of the Marmoset Monkey (*Hapale jactans* and *penicillata*) after hardening in bichromate of potash; the sections were stained by Weigert's and also by Pal's hæmatoxylin methods, whereby the fibres are differentiated. In this way, a complete series of sections was made in the sagittal and horizontal planes, and almost a complete series in the frontal direction, and by combining the appearances found in the three planes, a mental picture of the whole could thus be obtained.

In the description of this brain, emphasis is laid on its small size, which renders it very easy of manipulation, while, from its high position in the animal scale, its general arrangement is comparable

Fig. 1



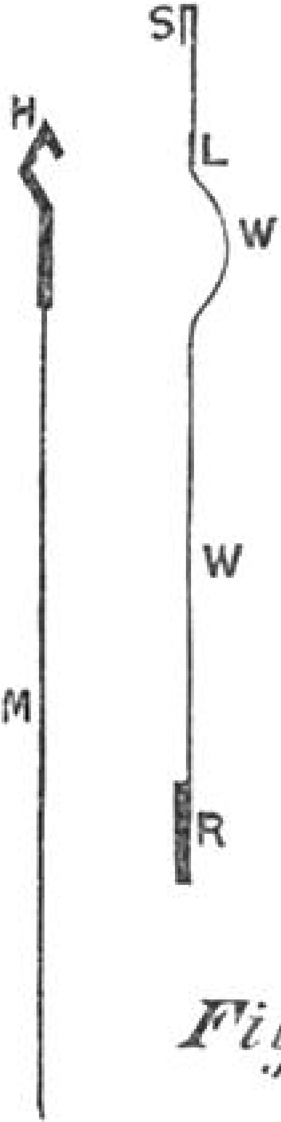


Fig. 2